

Topographic Effects on Stratified Flows

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LONG-TERM GOALS

To use measurements and develop theory for stratified flow past topography. To understand the relevant processes, including establishment of the downslope flow, the role of boundary layer separation, entrainment, as well as the generation, propagation and dissipation of internal solitary waves.

OBJECTIVES

To analyze the behavior of stratified flows in the neighborhood of a variety of topographic features, in channels, inlets, straits and in the open ocean, using both measurements and theory, so as to understand the relevant dynamics.

APPROACH

We have carried out observations of both tidally forced and density forced controlled flows using ship based instrumentation and aircraft. The observations have been acquired over the Oregon shelf, where we studied the generation and propagation of internal solitary waves, and in Knight Inlet where we have tracked the behavior of strongly forced flow and its formation of large amplitude internal solitary waves and undular bores. Laboratory modeling efforts have primarily made use of two layer representations, but also include effects of entrainment.

WORK COMPLETED

The analysis of strongly forced flow over a sill (Armi and Farmer, 2002) was completed. Observations of internal solitary waves over the Oregon continental shelf were analyzed so as to determine their evolution under the influence of changing stratification, current and water depth (Moum et al., 2003). Results from a recent experiment in Knight Inlet, BC, focused on the generation and propagation of nonlinear internal waves near the sill during ebb tide (Cummins et al., 2003). In all these studies, high quality echo-sounder and velocity measurements were complemented by aerial photographs of the surface signatures of the internal waves.

RESULTS

Internal solitary waves are widely observed in both the atmosphere and ocean. Notwithstanding the interest they have aroused in various contexts, the generation of internal solitary waves remains poorly

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understood. Tidal flow over a sill generates solitary wave trains very close to the area of topographic interaction. These include the formation of waves following relaxation of a hydraulic response, waves generated through finite amplitude intrusions, and the escape of lee waves trapped over a sill.

In Cummins et al. (2003), we examined the formation of solitary-like internal waves through new observations of a stratified flow over topography. The resulting interaction produces long internal-wave trains with a striking surface signature. Acoustic measurements and photographs of the sea surface, along with a numerical simulation, document the generation and propagation of a group of nonlinear internal waves. These results demonstrate that the essential aspect of the wave-generating mechanism involves upstream influence arising in hydraulic flow over topography.

In Moum et al. (2003) we collaborated on detailed observation of the structure within internal solitary waves propagating shoreward over Oregon's continental shelf. A persistent feature is high acoustic backscatter beginning in the vicinity of the wave trough and continuing through the trailing edge and wake. An example of is shown in figure 1.

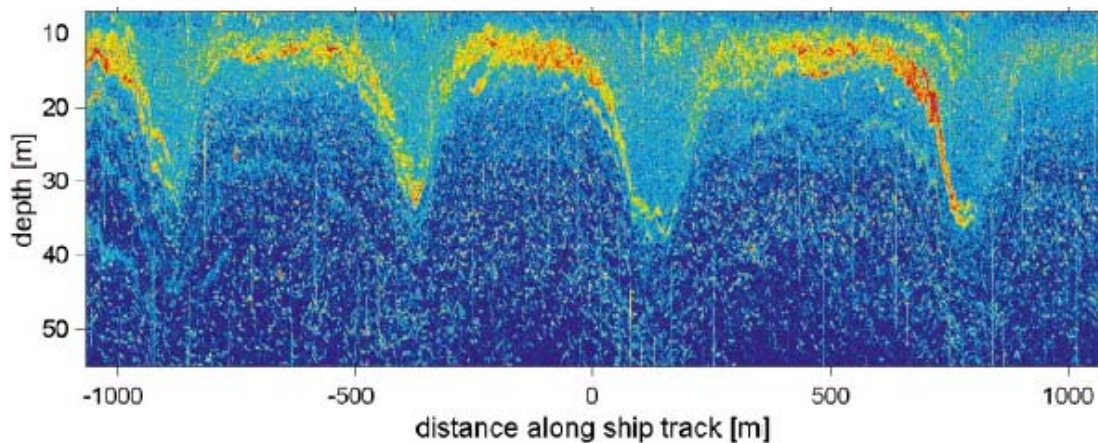


Figure 1. An acoustic backscatter image showing a sequence of internal solitary waves propagating from left to right. This acoustic image was made as the ship steamed west from 2128-2137 UTC on 01 Oct 2001. Red indicates high intensity backscatter and blue indicates low intensity. The ships track is shown in figure 2.

The collection of the image shown in figure 1 and associated velocity and turbulence measurements was coordinated with aircraft tracking along the internal wave and aerial photographs shown in figure 2. These show the two-dimensionality of these features over many kilometers.

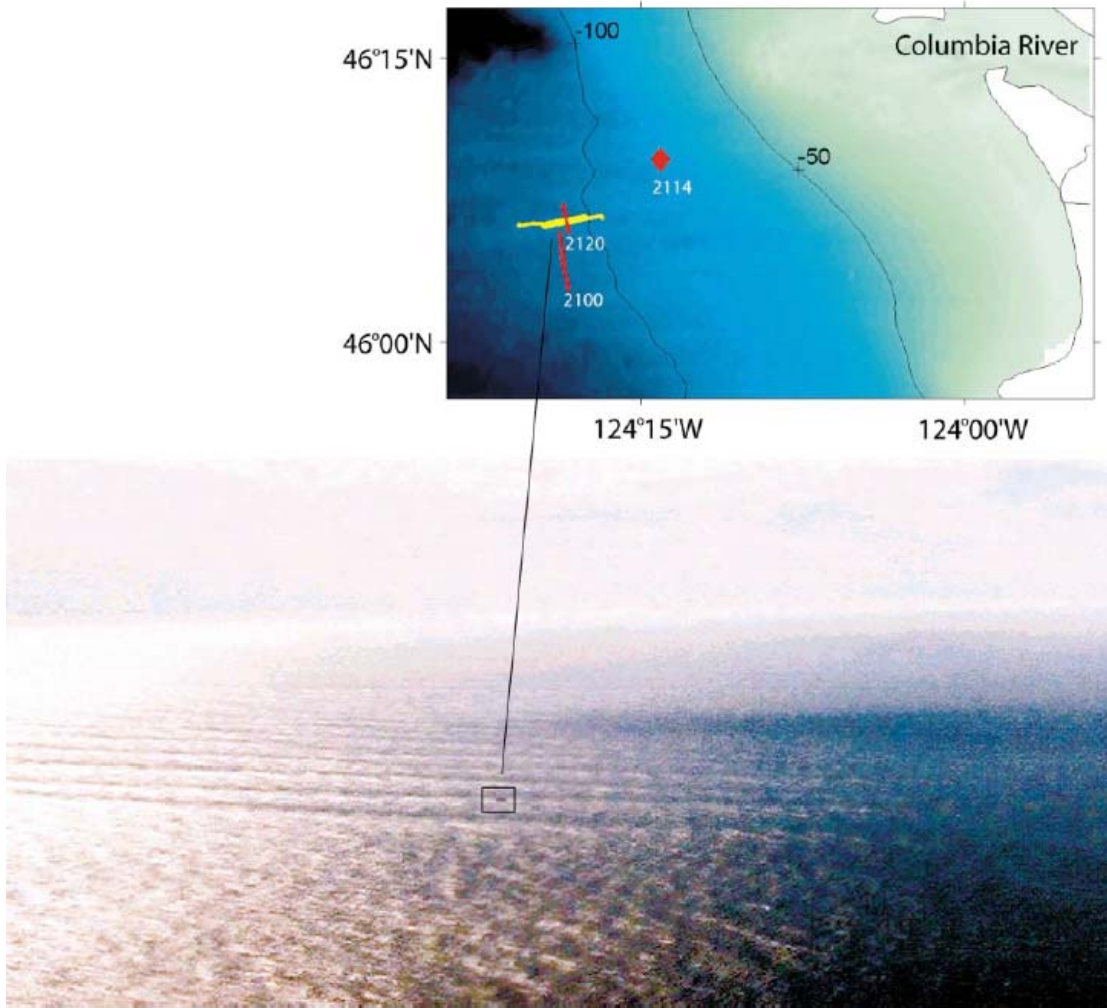


Figure 2. Location of experiment off the Oregon Coast with the ships track over the period 2000-2200 UTC 01 Oct 2001 shown in yellow. A coordinated aircraft flight was made both to track wave fronts and to photograph the surface signature of the internal solitary waves shown in figure 1. The photograph at the bottom was taken from the aircraft at the location of the red diamond at 2114 UTC. Aircraft tracks along the wave front before and after the photograph was taken are shown in red. The ship is located with the box in the photograph. Alternating bright and dark bands in the photograph are a consequence on internal wave induced convergence (bright, due to enhanced capillary wave field) and divergence (dark, due to reduced capillary wave field).

Among the results this work demonstrated that increased small scale strain ahead of the wave trough compresses select density interfaces, thereby locally increasing the stratification and is followed by a sequence of overturning, high-density microstructure and turbulence at the coincident high acoustic backscatter interface.

IMPACT/APPLICATIONS

These results contribute to our ability to predict flows in stratified coastal environments, especially in the presence of topography and tidal or estuarine forcing, by demonstrating the underlying mechanisms. The stratified flow results apply as well to severe downslope winds (Mayr et al., 2003) which occur in the atmosphere and are a hazard to aircraft.

RELATED PROJECTS

Jim Moum's ONR funded studies of topographic flows over the Oregon Shelf.

David Farmer's ONR funded studies of stratified topographic flow and the generation of internal solitary waves.

Collaboration with Patrick Cummins on numerical modeling of upstream internal wave generation.

REFERENCES

Armi, L. and Farmer, D. 2002. Stratified flow over topography: Bifurcation fronts and transition to the uncontrolled state. *Proc. Roy. Soc. Lond. A* . 458, 513-538.

Cummins, P.F., Vagle, S., Armi, L. and Farmer, D. 2003. Stratified flow over topography: Upstream influence and generation of nonlinear internal waves. *Proc. Roy. Soc. Lond. A*, 459, 1467-1487.

Mayr, G. J., Armi, L., Arnold, S., Banta, R. M., Darby, L. S., Durran, D. R., Gabersek, S., Gohm, A., Mayr, R., Mobbs, S., Nance, L. B., Vergeiner, I. Vergeiner, J. and Whiteman, C. D. 2003. GAP flow measurements during the Mesoscale Alpine Programme. *Met. and Atm. Phys.*, in press.

Moum, J.N., Farmer, D.M., Smyth, W.D., Armi, L., and Vagle, S. 2003. Structure and generation of turbulence at interfaces strained by internal solitary waves propagating shoreward over the continental shelf. *J. Phys. Oceanography*, 33, 2093-2112.

PUBLICATIONS

Armi, L. and Farmer, D. 2002. Stratified flow over topography: Bifurcation fronts and transition to the uncontrolled state. *Proc. Roy. Soc. Lond. A* . 458, 513-538. (published, refereed)

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Mayr, G. J., Armi, L., Arnold, S., Banta, R. M., Darby, L. S., Durran, D. R., Gabersek, S., Gohm, A., Mayr, R., Mobbs, S., Nance, L. B., Vergeiner, I. Vergeiner, J. and Whiteman, C. D. 2003. GAP flow measurements during the Mesoscale Alpine Programme. *Met. and Atm. Phys.* (in press, refereed)

Eastwood, C. D., Armi, L. and Lasheras, J. C. 2003. The break-up of immiscible fluids in turbulent flows. *J. Fluid Mech.* (in press, refereed)